

PATENT



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QUASI-DIFFERENTIAL POWER AMPLIFIER AND METHOD

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QUASI-DIFFERENTIAL POWER AMPLIFIER AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to integrated circuit (IC) amplifiers, and more specifically to IC power amplifiers for driving three-wire stereo headphones in small portable stereo systems.

2. Description of the Related Art

Small portable stereo systems generally include a digital audio source, a digital volume control, a digital-to-analog converter (DAC), and an integrated circuit (IC) power amplifier for driving analog output signals to stereo headphones. The vast majority of these stereo headphones have a three-wire connection consisting of a left (L) terminal, a right (R) terminal, and a common (C) terminal. The IC power amplifier typically includes a first amplifier that drives a left (L) channel signal connected to the left (L) terminal and a second amplifier that drives a right (R) channel signal connected to the right (R) terminal. The common (C) terminal of the headphone is generally connected to system ground (GND).

Because of the low voltage supplies used to power these portable stereo systems, the dynamic range and maximum power delivered by typical power amplifiers to the stereo headphones are limited. For example, with a typical IC power amplifier and a low voltage supply, such as a 3 volt supply, the left (L) and right (R) channel outputs can be driven from approximately 0.5 volts to 2.5 volts. This signal range limits the maximum sine wave that may be delivered to the headphone to about 0.707 volts rms and limits the maximum power into each channel to about $(0.707 \text{ V rms})^2 / 32\Omega = 15 \text{ mW}$. In addition, with a typical IC power amplifier, the left (L) and right (R) terminals must be AC coupled to the IC power amplifier through large capacitors to provide a low frequency pole for the left (L) and right (R) headphone speakers. For

1 example, assuming right (R) and left (L) headphone speakers having a typical value of about
2 32Ω , the coupling capacitors must be about $100\ \mu\text{F}$ to place the low frequency RC pole at about
3 50 Hz. The cost of two large capacitors, such as $100\ \mu\text{F}$ capacitors, is a significant problem for
4 these types of systems.

5
6 To eliminate the need for the AC coupling capacitors, a third amplifier may be added to
7 the IC power amplifier to drive the common (C) terminal of the headphone at a fixed common
8 mode (CM) voltage (V_{CM}). This fixed common mode driver approach, however, requires that the
9 third amplifier have approximately twice the current drive capability of the left (L) channel and
10 right (R) channel amplifiers at peak current loads. This additional high power third amplifier
11 significantly increases the power consumption of the IC power amplifier and does not increase
12 the maximum power deliverable to the headphone. For example, in a typical system, there is a
13 particular volume control setting that will cause the power amplifier to just barely clip the signal
14 when given a full scale signal from the digital audio source. Because the program material being
15 processed by the digital audio source typically does not contain any full scale signals, the volume
16 control will often have settings that exceed this clipping limit. Assuming that the output of the
17 right (R) and left (L) channel drive amplifiers can swing from $V_{\text{CM}} - 1$ volts to $V_{\text{CM}} + 1$ volts
18 without clipping, the maximum voltage that the IC power amplifier in the fixed common mode
19 approach can deliver to the headphones without clipping is about $2 V_{\text{pp}}$ (volts peak-to-peak).
20

21 SUMMARY OF THE INVENTION

22
23 In accordance with the present invention, a quasi-differential power amplifier enhances
24 drive capability and dynamic range by providing a first output signal, a second output signal, and
25 a common mode output signal that are each a combination of a first and a second input signals.
26 In one embodiment, the common mode output signal is used as feedback to the first and second
27 output signals. In a further embodiment, the input signals are digital, and the quasi-differential
28 power amplifier includes a first and second digital-to-analog converters coupled to the first and
29 second input signals, a first amplifier driving the first output signal, a second amplifier driving
30 the second output signal, and a third amplifier driving the common mode output signal. In one

1 application, the input signals are a right and left channel audio input signals, and the output
2 signals are used to drive three-wire stereo headphones.

4 **BRIEF DESCRIPTION OF THE DRAWINGS**

6 FIG. 1 is a block diagram of a system including a quasi-differential power amplifier
7 according to the present invention.

9 FIG. 2 is a block diagram of an embodiment for a quasi-differential power amplifier
10 according to the present invention.

12 FIG. 3 is a block diagram of an alternative embodiment for a quasi-differential power
13 amplifier according to the present invention.

15 FIG. 4 is a circuit configuration for the quasi-differential power amplifier depicted in
16 FIG. 3.

18 FIG. 5 is a block diagram of another alternative embodiment of a quasi-differential power
19 amplifier according to the present invention.

21 **DESCRIPTION OF THE PREFERRED EMBODIMENTS**

23 Referring to FIG. 1, a system 150 is shown that includes a quasi-differential power
24 amplifier 100 connected to a digital-to-analog converter (DAC) 106 and three-wire headphones
25 108. System 150 also includes a digital audio source 102 connected to a digital volume control
26 block 104, which is in turn connected to a DAC 106. The digital audio source 102 provides a left
27 (L) channel output 124 and a right (R) channel output 126 to the digital volume control 104,
28 which in turn provides a volume adjusted left (L) channel output 120 and a volume adjusted right
29 (R) channel output 122 to the DAC 106. The DAC 106 provides an analog left (L) channel
30 output 116 and an analog right (R) channel output 118 to the quasi-differential power amplifier

1 100. The quasi-differential power amplifier 100 drives the three input terminals of the
2 headphone 108 with left (L) channel signal 112, right (R) channel signal 110, and common mode
3 (CM) signal 114.

4
5 In one embodiment, the system 150 may be a small portable stereo system including
6 three-wire stereo headphones 108. It is noted that the embodiment for system 150 depicted in
7 FIG. 1 is an example embodiment and that alternative implementations could be designed and
8 utilized. For example, the left (L) channel output 116 and right (R) channel output 118 could be
9 any two signals desired to be input to the quasi-differential power amplifier 100, and the left (L)
10 channel signal 112, right (R) channel signal 110, and common mode (CM) signal 114 could be
11 the output signals of the quasi-differential power amplifier 100. Thus, the input and output
12 signals are not required to relate to a left (L) and right (R) channel stereo signal.

13
14 FIG. 2 shows an embodiment for a quasi-differential power amplifier 100 according to
15 the present invention. The analog left (L) channel output 116 from DAC 106 is connected as a
16 positive input to adders 210 and 216 and is connected as a negative input to adder 214. The
17 analog right (R) channel output 118 from DAC 106 is connected as a positive input to adders 214
18 and 218 and is connected as a negative input to adder 210. A common mode voltage (V_{CM}) 226
19 is connected as a negative input to adders 216 and 218. The outputs of adders 216 and 218 are
20 connected as positive inputs to adder 212. The outputs 232, 234, and 236 of adders 210, 212,
21 and 214 are connected to amplifiers 202, 204, and 206, respectively, which each have an inverted
22 gain of $-\frac{1}{2}$. The outputs of amplifiers 202, 204, and 206 are connected as positive inputs to
23 adders 220, 224, and 222, respectively, which also receive the common mode voltage (V_{CM}) 226
24 as a positive input. The output of adder 220 is the right (R) channel signal 110; the output of
25 adder 222 is the left (L) channel signal 112; and the output of adder 224 is the common mode
26 (CM) signal 114. To simplify FIG. 2, the left (L) and right (R) channel analog audio inputs 116
27 and 118 from DAC 106 are shown as single-ended signals, although it is understood that these
28 signals may be implemented as differential or single-ended signals, as desired.

In operation, the left (L) channel analog audio input 116 from DAC 106 consists of a signal voltage (V_L) plus a common mode voltage (V_{CM}). Similarly, the right (R) channel analog audio input 118 from DAC 106 consists of a signal voltage (V_R) plus a common mode voltage (V_{CM}). Although analog audio inputs 116 and 118 are shown as single lines in FIG. 2, it is understood that they may be implemented as differential signals, allowing them to swing $4 V_{pp}$. The output 232 of adder 210 is $(V_L + V_{CM}) - (V_R + V_{CM}) = V_L - V_R$. The output 236 of adder 214 is $(V_R + V_{CM}) - (V_L + V_{CM}) = V_R - V_L$. The output 234 of adder 212 is $(V_R + V_{CM}) + (V_L + V_{CM}) - 2V_{CM} = V_R + V_L$. The left (L) channel output signal (L_{OUT}) 112 from adder 222, the right (R) channel output signal (R_{OUT}) 110 from adder 220, and the common mode (CM) output signal (CM_{OUT}) 114 from adder 226 are as follows:

$$L_{OUT} = V_{CM} + (V_L - V_R)/2;$$

$$R_{OUT} = V_{CM} + (V_R - V_L)/2; \text{ and}$$

$$CM_{OUT} = V_{CM} - (V_L + V_R)/2.$$

The signals which are actually applied to the right and left speakers of the headphone 108 are the following:

$$L_{speaker} = L_{OUT} - CM_{OUT} = [V_{CM} + (V_L - V_R)/2] - [V_{CM} - (V_L + V_R)/2] = V_L; \text{ and}$$

$$R_{speaker} = R_{OUT} - CM_{OUT} = [V_{CM} + (V_R - V_L)/2] - [V_{CM} - (V_R + V_L)/2] = V_R.$$

Although it is not practical to drive the left (L) and right (R) terminals of the headphone fully differentially, the quasi-differential power amplifier of the present invention provides substantially greater drive capability and increased dynamic range and reduces power consumption compared to prior single-ended drive techniques, such as those used by prior grounded power amplifier and fixed common mode amplifier approaches. The quasi-differential power amplifier of the present invention achieves these advantages by providing a left channel output signal, a right channel output signal, and a common mode output signal that are each a combination of the left and right channel input signals.

An example of this advantage may be seen in the situation where $V_L = V_{CM} + 2$ volts and $V_R = V_{CM}$. Assuming these values, CM_{OUT} and R_{OUT} will both be driven to values of $V_{CM} - 1$ volt, while L_{OUT} will be driven to a value of $V_{CM} + 1$ volt. As desired, a 2 volt signal will ultimately be

1 applied to the left speaker, while a 0 volt signal is applied to the right speaker. Thus, for the
 2 quasi-differential power amplifier of the present invention, a non-clipped signal will be applied
 3 to each speaker. In contrast, for the prior grounded power amplifier and fixed common mode
 4 amplifier approaches, a clipped signal of +1 volt would be applied to the left speaker due to
 5 clipping of the V_L signal to $V_{CM} + 1$ volt, and a 0 volt signal would be applied to the right
 6 speaker. This case illustrates, therefore, the potential for increased signal swing available
 7 utilizing the quasi-differential power amplifier according to the present invention.

8
 9 One potential drawback for the embodiment depicted in FIG. 2, however, is that the
 10 signal level which causes the right (R) channel to clip is dependent on the signal level in the left
 11 (L) channel and vice versa. Assuming that the output of the right channel signal (R_{OUT}) 110 and
 12 left channel signal (L_{OUT}) 112 can swing from $V_{CM} - 1$ volts to $V_{CM} + 1$ volts without clipping,
 13 the power amplifier 100 will clip whenever the instantaneous value of $|V_L - V_R| > 2$. Three
 14 different signal level conditions illustrate example clipping situations. In a first case, assuming
 15 $|V_L|$ and $|V_R| \leq 1$ volt, neither output channel will be clipped, regardless of polarity of the
 16 signals. In a second case, assuming $V_L = +2$ volts and $V_R = -2$ volts, CM_{OUT} will be driven to a
 17 value of V_{CM} . Ideally without clipping, L_{OUT} and R_{OUT} would be driven to $V_{CM} + 2$ volts and V_{CM}
 18 $- 2$ volts, respectively. Because L_{OUT} will clip at $V_{CM} + 1$ volt and R_{OUT} will clip at $V_{CM} - 1$ volt,
 19 however, a clipped signal will ultimately be applied to each speaker. An analogous situation
 20 occurs if $V_L = -2$ volts and $V_R = +2$ volts. In a third case, assuming V_L and $V_R = +2$ volts,
 21 CM_{OUT} would be ideally driven to a value of $V_{CM} - 2$ volts, but will clip at $V_{CM} - 1$ volt. Because
 22 the L_{OUT} and R_{OUT} signals will both be at V_{CM} , a clipped signal will ultimately be delivered to
 23 both speakers. An analogous situation occurs when both V_L and $V_R = -2$ volts.

24
 25 Considering the above clipping situations, the embodiment of FIG. 2 will encounter
 26 clipping for two primary reasons — large signals of opposite polarity (case two) and large
 27 signals of the same polarity (case three). In second case situations, the clipping occurs at the
 28 L_{OUT} and R_{OUT} terminals. In third case situations, the clipping occurs at the CM_{OUT} terminal,
 29 while the L_{OUT} and R_{OUT} terminals are at V_{CM} . By incorporating a mechanism to detect clipping
 30 on the CM_{OUT} terminal and to adjust the L_{OUT} and R_{OUT} terminals to compensate, the third case

1 clipping situation may be avoided. As discussed further below, second case situations are
 2 relatively rare and are less of a concern.

3
 4 FIG. 3 shows an alternative embodiment for a quasi-differential headphone power
 5 amplifier 100 that provides a feedback mechanism to compensate for third case clipping
 6 situations. The analog left (L) channel output 116 from DAC 106 is connected as a positive
 7 input to adder 301, and the analog right (R) channel output 118 from DAC 106 is connected as a
 8 positive input to adder 303. Adders 303 and 301 also receive the common mode voltage (V_{CM})
 9 226 as a negative input. The output 312 of adder 303 is connected as a positive input to adders
 10 210 and 212. The output 314 of adder 303 is connected as a positive input to adders 214 and
 11 212. The output 320 of adder 212 is connected to amplifier 204, which has a negative gain of $-\frac{1}{2}$.
 12 The output of amplifier 204 is connected as a positive input to adders 210 and 214. The
 13 outputs 316 and 318 of adders 210 and 214 are connected to amplifiers 202 and 206,
 14 respectively, which each have a positive gain of +1. The outputs of amplifiers 202, 204, and 206
 15 are connected as positive inputs to adders 220, 224, and 222, respectively, which also receive the
 16 common mode voltage (V_{CM}) 226 as a positive input. As in FIG. 2, the output of adder 220 is the
 17 right (R) channel signal 110; the output of adder 222 is the left (L) channel signal 112; and the
 18 output of adder 224 is the common mode (CM) signal 114.

19
 20 In operation, a portion of the CM_{OUT} signal from the output of amplifier 204 is provided
 21 as feedback to adders 210 and 214. This feedback is combined with the left (L) and right (R)
 22 channel signals to adjust the resulting L_{OUT} and R_{OUT} signal levels to compensate for any clipping
 23 which may occur at the CM_{OUT} terminal. As with FIG. 2, the left (L) channel analog audio input
 24 116 from DAC 106 consists of a signal voltage (V_L) plus a common mode voltage (V_{CM}).
 25 Similarly, the right (R) channel analog audio input 118 from DAC 106 consists of a signal
 26 voltage (V_R) plus a common mode voltage (V_{CM}). The output 314 of adder 301 is $(V_L + V_{CM}) -$
 27 $V_{CM} = V_L$. The output 312 of adder 303 is $(V_R + V_{CM}) - V_{CM} = V_R$. The output 320 of adder 212
 28 is $V_L + V_R$ and is applied to amplifier 204. Amplifier 204 produces an output signal 322 that is
 29 used as a feedback (FB) signal to the left and right signal paths. The output 322 is $FB = (-\frac{1}{2})(V_L$

1 + V_R). The amplifier 204, and therefore the output signal 322, may be assumed to clip at certain
2 values such as +1 volt or -1 volt.

3
4 The output 318 of adder 214 is $V_L + FB$. In a non-clipped situation, $FB = (-1/2)(V_L + V_R)$,
5 and the output 318 will be $V_L + FB = V_L + (-1/2)(V_L + V_R) = (V_L - V_R)/2$. Similarly, the output
6 316 of adder 210 is $V_R + FB$. In a non-clipped situation, $FB = (-1/2)(V_L + V_R)$, and the output 316
7 will be $V_R + FB = V_R + (-1/2)(V_L + V_R) = (V_R - V_L)/2$. The output 318 is fed to amplifier 206 to
8 provide output 324, and output 316 is fed to amplifier 202 to provide output 326. As with
9 amplifier 204 above, amplifiers 202 and 206 may be assumed to clip at certain values such as +1
10 volt or -1 volt.

11
12 In non-clipped situations, the left (L) channel output signal (L_{OUT}) 112 from adder 220,
13 the right (R) channel output signal (R_{OUT}) 110 from adder 224, and the common mode (CM)
14 output signal (CM_{OUT}) 114 from adder 226 are as follows:

$$15 \quad L_{OUT} = V_{CM} + (V_L - V_R)/2;$$

$$16 \quad R_{OUT} = V_{CM} + (V_R - V_L)/2; \text{ and}$$

$$17 \quad CM_{OUT} = V_{CM} - (V_L + V_R)/2.$$

18 The signals which are actually applied to the right and left speakers of the headphone 108 in non-
19 clipped situations are the following:

$$20 \quad L_{speaker} = L_{OUT} - CM_{OUT} = [V_{CM} + (V_L - V_R)/2] - [V_{CM} - (V_L + V_R)/2] = V_L; \text{ and}$$

$$21 \quad R_{speaker} = R_{OUT} - CM_{OUT} = [V_{CM} + (V_R - V_L)/2] - [V_{CM} - (V_R + V_L)/2] = V_R.$$

22
23 For the embodiment of FIG. 3 and again assuming clipping at $V_{CM} \pm 1$ volt, the signal
24 applied across the left and right speakers will clip whenever the instantaneous value of $|V_L - V_R|$
25 > 2 , or when $|V_L|$ or $|V_R| > 2$. Considering the third case situation above for this
26 embodiment with V_L and $V_R = +2$ volts, the CM_{OUT} signal would ideally be driven to $V_{CM} - 2$
27 volts, and the L_{OUT} signal and the R_{OUT} signal would ideally be driven to V_{CM} . According to the
28 equations above, therefore, the desired resulting ideal signals to the left and right speakers are
29 $L_{speaker} = R_{speaker} = +2$ volts. Because of clipping in the amplifier 204, however, the output signal

1 322 of amplifier 204 will be clipped to -1 volt, and the CM_{OUT} signal will be clipped to $V_{CM} - 1$
 2 volt.

3
 4 The feedback (FB) signal 322 applied to adders 210 and 214 in the left and right channel
 5 paths compensates for this clipping condition. Because this feedback signal is also not ideal,
 6 having been clipped at -1 volt, the output 316 of adder 210 and the output 318 of adder 214 will
 7 adjust to $+1$ volt instead of an ideal 0 volts. For this clipped situation, therefore, the left and right
 8 channel output signals 112 (L_{OUT}) and 110 (R_{OUT}) will adjust to produce $L_{OUT} = R_{OUT} = V_{CM} + 1$
 9 volt instead of the ideal V_{CM} volts. The resulting signal actually sent to the left and right
 10 speakers will then be $L_{speaker} = L_{OUT} - CM_{OUT} = (V_{CM} + 1) - (V_{CM} - 1) = +2$ volts, and $R_{speaker} =$
 11 $R_{OUT} - CM_{OUT} = (V_{CM} + 1) - (V_{CM} - 1) = +2$ volts. Thus, the present invention provides the
 12 desired resulting signal to the left and right speakers even though the common mode output
 13 signal was clipped at $V_{CM} - 1$ volt.

14
 15 The quasi-differential power amplifier of the present invention, therefore, provides
 16 particularly advantageous results for case three situations where audio program material contains
 17 a large imbalance in signal levels or that contains signals in which the peak excursions are
 18 largely in phase with each other. For case two situations, in which signals have peak excursions
 19 which are perfectly out of phase, the quasi-differential power amplifier of the present invention
 20 does not tend to improve performance and clips at substantially the same point as the fixed
 21 common mode voltage approach. However, actual peak levels in the material being processed by
 22 the digital audio source occur infrequently and are perfectly out of phase with each other only a
 23 small percentage of the time. Thus, case two situations are less of a concern.

24
 25 Referring now to FIG. 4, a circuit implementation is shown for the quasi-differential
 26 headphone power amplifier 100 depicted in the block diagram of FIG. 3. DAC 106 includes a
 27 left (L) channel path DAC 402 and a right (R) channel path DAC 404 that drive the power
 28 amplifier 100. DACs 402 and 404 may be fully-differential switched-capacitor DACs. The
 29 volume adjusted left (L) channel output 120 is an input to the left (L) channel DAC 402.
 30 Similarly, the volume adjusted right (R) channel output 122 is an input to the right (R) channel

1 DAC 404. Common mode voltage (V_{CM}) 226 is an additional input to both left (L) channel DAC
 2 402 and right (R) channel DAC 404. The positive and negative outputs of left (L) channel DAC
 3 402 make up the analog left (L) channel output 116 from DAC 106, which is a differential input
 4 to quasi-differential power amplifier 100. The positive and negative outputs of right (R) channel
 5 DAC 404 make up the analog right (R) channel output 118 from DAC 106, which is a
 6 differential input to the quasi-differential power amplifier 100. It is noted that the embodiment
 7 for DAC 106 depicted in FIG. 4 is an example embodiment and that alternative implementations
 8 including a larger or smaller number of DACs or different DAC circuitry could be designed and
 9 utilized.

10
 11 Quasi-differential power amplifier 100 includes a left (L) channel operational amplifier
 12 (OPAMP) 410 driving the left (L) channel signal 112, a right (R) channel OPAMP 414 driving
 13 the right (R) channel signal 110, and a common mode OPAMP 412 driving the common mode
 14 (CM) signal 114. OPAMPs 410, 412, and 414 are connected to a power supply (V_{dd}) 420, which
 15 may be 3 volts, and a circuit ground (GND) 422. The negative differential output of left (L)
 16 channel DAC 402 is connected to the negative input terminal of OPAMP 410 through a resistor
 17 432. The positive differential output of left (L) channel DAC 402 is connected through a resistor
 18 434 to the positive input terminal of OPAMP 410 and through a resistor 438 to a negative input
 19 terminal of OPAMP 412. The negative differential output of right (R) channel DAC 404 is
 20 connected to the negative input terminal of OPAMP 414 through a resistor 446. The positive
 21 differential output of right (R) channel DAC 404 is connected through a resistor 444 to the
 22 positive input terminal of OPAMP 414 and through a resistor 440 to a negative input terminal of
 23 OPAMP 412. As feedback, the output of OPAMP 412 is connected to the negative input
 24 terminal of OPAMP 412 through resistor 442, to the positive input terminal of OPAMP 410
 25 through resistor 448, and to the positive input of OPAMP 414 through resistor 450. The resistors
 26 432, 434, 436, 438, 440, 442, 444, 446, 448, and 450 may be matched resistors. It is noted that
 27 the embodiment for quasi-differential power amplifier 100 depicted in FIG. 4 is an example
 28 embodiment and that alternative implementations including a larger or smaller number of
 29 amplifiers or different amplifier circuitry could be designed and utilized.

1 The three-wire headphones 108 include a left (L) channel speaker represented by resistor
 2 (R_{LEFT}) 406 and a right (R) channel speaker represented by resistor (R_{RIGHT}) 408, which may each
 3 be 32 Ω . Resistor (R_{LEFT}) 406 is connected between the left (L) channel signal 112, which is
 4 driven by the left (L) channel OPAMP 414, and to the common mode (CM) signal 114, which is
 5 driven by the common mode OPAMP 412. Resistor (R_{RIGHT}) 408 is connected between the right
 6 (R) channel signal 110, which is driven by the right (R) channel OPAMP 414, and the common
 7 mode (CM) signal 114, which is driven by the common mode OPAMP 412.

8
 9 In operation, the left (L) channel path DAC 402 provides a positive differential output
 10 (V_{L+}) and a negative differential output (V_{L-}), and the right (R) channel path DAC 404 provides a
 11 positive differential output (V_{R+}) and a negative differential output (V_{R-}). The common mode
 12 signal output (CM_{OUT}) 114 driven by OPAMP 412 is $CM_{OUT} = V_{CM} - V_{R+} - V_{L+}$. This signal is
 13 fed back to OPAMP 410 and OPAMP 414 and is used as a reference signal for the differential to
 14 single-ended conversion performed by OPAMP 410 and OPAMP 414. The output signal (L_{OUT})
 15 of the left channel OPAMP 410 is $L_{OUT} = V_{L+} - V_{L-} + CM_{OUT}$. In ideal situations without clipping
 16 of CM_{OUT} , L_{OUT} will be $L_{OUT} = V_{CM} - V_{R+} - V_{L-}$. Similarly, the output signal (R_{OUT}) of the right
 17 channel OPAMP 414 is $R_{OUT} = V_{R+} - V_{R-} + CM_{OUT}$. And in ideal situations without clipping,
 18 R_{OUT} will be $R_{OUT} = V_{CM} - V_{L+} - V_{R-}$. In a non-clipping situation, therefore, the signals which are
 19 actually applied to the right and left speakers 406 and 408 of the headphone 108 are the
 20 following:

$$21 \quad L_{speaker} = L_{OUT} - CM_{OUT} = [V_{CM} - V_{R+} - V_{L-}] - [V_{CM} - V_{R+} - V_{L+}] = V_{L+} - V_{L-}; \text{ and}$$

$$22 \quad R_{speaker} = R_{OUT} - CM_{OUT} = [V_{CM} - V_{L+} - V_{R-}] - [V_{CM} - V_{R+} - V_{L+}] = V_{R+} - V_{R-}.$$

23 These outputs correlate to the differential output of the DACs 402 and 404, which could
 24 potentially swing $4 V_{pp}$.

25
 26 Similar to the discussion above with respect to FIG. 3, the embodiment of the present
 27 invention depicted in FIG. 4 handles certain clipping conditions on CM_{OUT} through the use of the
 28 CM_{OUT} signal as feedback to the right and left channel signals. For example, assuming the $V_{R+} =$
 29 $V_{L+} = +1$ volts and the $V_{R-} = V_{L-} = -1$ volts, CM_{OUT} would ideally be driven to $CM_{OUT} = V_{CM} - 2$
 30 volts, and L_{OUT} and R_{OUT} would ideally be driven to $L_{OUT} = R_{OUT} = V_{CM}$. Thus, without clipping,

1 the signals actually applied to the left and right speakers would be $R_{\text{speaker}} = L_{\text{speaker}} = +2$ volts.
 2 Assuming now that CM_{OUT} clips at $V_{\text{CM}} - 1$ volts, L_{OUT} and R_{OUT} will adjust accordingly so that
 3 the resulting speaker output signals are still ideal. In particular, L_{OUT} will adjust such that $L_{\text{OUT}} =$
 4 $V_{L+} - V_{L-} + CM_{\text{OUT}} = +1 - (-1) + (V_{\text{CM}} - 1) = V_{\text{CM}} + 1$ volts. Similarly, R_{OUT} will adjust such that
 5 $R_{\text{OUT}} = V_{R+} - V_{R-} + CM_{\text{OUT}} = +1 - (-1) + (V_{\text{CM}} - 1) = V_{\text{CM}} + 1$ volts. Even with clipping as
 6 assumed above, therefore, the signals actually applied to the left and right speakers according to
 7 the embodiment of the present invention in FIG. 4 will be $R_{\text{speaker}} = L_{\text{speaker}} = +2$ volts.

8
 9 It should be noted that rather than an analog implementation, the quasi-differential
 10 approach of the present invention could be implemented in the digital data path. In this case,
 11 DACs and amplifiers could be used to drive the outputs of digital processors to the desired signal
 12 output levels. This digital approach has the advantage that the differential to single-ended signal
 13 combination is performed in the digital domain, but has the disadvantage of requiring additional
 14 DACs.

15
 16 FIG. 5 depicts an example embodiment 500 for such a digital path approach for a quasi-
 17 differential power amplifier according to the present invention. Signal 502 may be a digital left
 18 (L) channel audio input signal, and signal 504 may be a digital right (R) channel audio input
 19 signal. A common mode digital processor 504 may receive both the digital left (L) and right (R)
 20 channel audio input signals 502 and 504. The common mode digital processor 504 may process
 21 these two input signals as desired and provide an output signal 512 that is dependent upon the
 22 left (L) and right (R) channel audio input signals 502 and 504. This common mode output signal
 23 512 may then be used as the feedback signal to the left and right channel signal paths.

24
 25 The left channel digital processor 506 may receive the digital left (L) channel audio input
 26 signal 502 and the feedback signal 512. The left channel digital processor 506 may process these
 27 two input signals as desired and provide an output signal 507 that is dependent upon the left (L)
 28 channel input signal 502 and the common mode feedback signal 512. Similarly, the right
 29 channel digital processor 510 may receive the digital right (R) channel audio input signal 504
 30 and the feedback signal 512. The right channel digital processor 510 may process these two

1 input signals as desired and provide an output signal 511 that is dependent upon the right (R)
2 channel input signal 504 and the common mode feedback signal 512. Because the common
3 mode feedback signal 512 is dependent upon both the left (L) and right (R) channel audio input
4 signals 502 and 504, the output signal 507 from the left channel digital processor 506 and the
5 output signal 511 from the right channel digital processor 510 are also dependent upon both the
6 left (L) and right (R) channel audio input signals 502 and 504.

7
8 DACs 514, 516 and 518 may be used to convert the digital processor output signals 507,
9 512 and 511, respectively, to analog signals. Amplifiers 520, 522 and 524 may be connected to
10 DACs 514, 516 and 518, respectively, to drive the left channel output signal 526, the common
11 mode output signal 528, and the right channel output signal 530.